

DEQF Static Pressure as the Source of c , Λ , the Arrow of Time, and the Matter–Antimatter Bias

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Abstract

Proceeding from our earlier results in which the constant speed of light c and the cosmological constant Λ emerge from the *static* pressure of the Dark Energy Quantum Field (DEQF), we show that the *same* invariant pressure, denoted P_0 , also underwrites three macroscopic facts: (i) a preferred temporal orientation (the arrow of time), (ii) non-negative entropy production consistent with the Second Law, and (iii) a small forward-time bias in worldline weights that favors matter over antimatter. We formalize P_0 as a time-orienting background with unit selector U^μ and a vacuum coherence time $\tau(a)$ that together bias path measures. In a coarse-grained description this yields a strictly non-negative entropy production term; in a GUFT Lagrangian, it appears as a CPT-odd interaction $\mathcal{L}_{\text{int}} = \mu_t(a) U_\mu J_{B-L}^\mu$, with $\mu_t \propto P_0 \tau / M_*^2$, which produces a baryon asymmetry $\eta_B \propto (\mu_t/T)|_{T_{\text{FO}}}$. We state minimal postulates, derive the sign and scaling of the temporal-bias parameter, give consistency conditions (BBN/CMB and local constraints), and summarize falsifiable implications. All four phenomena $\{ c, \Lambda, \text{arrow of time, baryon bias} \}$ trace to one invariant P_0 .

Keywords: DEQF, static vacuum pressure, arrow of time, entropy production, baryogenesis, CPT-odd interactions

1 Introduction

The present paper advances a single-mechanism thesis: the *static* DEQF pressure P_0 that already explains c and Λ also sets the temporal arrow, ensures non-negative entropy production at coarse-grained level, and creates a tiny forward-time preference that yields the observed matter excess. Our contributions are: (i) a pressure-first set of postulates consistent with General Relativity (GR) and the GUFT program, (ii) a compact entropy argument based on modified detailed balance, and (iii) a GUFT Lagrangian term that produces a calculable baryon bias.

2 Recap from Papers I–II (Notation)

We adopt the following elements from prior work: (a) an invariant static pressure P_0 associated with the DEQF vacuum; (b) a vacuum coherence time $\tau(a)$ with present value τ_0 ; and (c) the comoving frame four-selector U^μ (future-directed, $U^\mu U_\mu = -1$, comoving $U^\mu = (1, 0, 0, 0)$). We use natural units $c = \hbar = 1$, metric signature $(-, +, +, +)$, scale factor a ($a=1$ today), and redshift $z = a^{-1} - 1$.

3 Postulates: Static Pressure and Temporal Selector

P0-selector postulate. The DEQF vacuum carries an invariant pressure P_0 and a coarse-grained time-orientation encoded by a unit timelike vector U^μ . The pair (P_0, U^μ) is homogeneous and isotropic in the comoving frame.

Coherence postulate. The DEQF has a vacuum coherence time $\tau(a)$ that controls how strongly the background can bias path measures over a proper-time interval; to leading order we take $\tau(a) = \tau_0 a^{-p}$ with constant slope $d \ln \tau / d \ln a = -p$.

Minimal coupling postulate. At low energies the only CPT-odd, gauge-invariant, rotationally symmetric operator linear in U^μ that biases matter versus antimatter is $\mathcal{L}_{\text{int}} = \mu_t(a) U_\mu J_{B-L}^\mu$ with $\mu_t(a)$ a scalar function built from P_0 , τ , and a heavy scale M_* .

4 Arrow of Time, Entropy, and the Second Law

We model the DEQF static pressure P_0 as selecting a forward temporal orientation via a unit timelike selector U^μ and a coherence time $\tau(a)$. At a coarse-grained level this induces a small time-odd correction to detailed balance over a proper-time step Δt :

$$\frac{W_{i \rightarrow j}}{W_{j \rightarrow i}} = \exp \left[\Delta S_{i \rightarrow j} + \varepsilon_t \frac{\Delta t}{\tau(a)} \right], \quad 0 < \varepsilon_t \ll 1, \quad (1)$$

where $W_{i \rightarrow j}$ are transition rates between coarse states, $\Delta S_{i \rightarrow j}$ is the stochastic entropy change (with $k_B = 1$), and ε_t quantifies the DEQF-induced time orientation.

Using the standard H -theorem machinery, the coarse-grained entropy production rate is

$$\dot{S} = \frac{1}{2} \sum_{i,j} (P_i W_{i \rightarrow j} - P_j W_{j \rightarrow i}) \ln \frac{W_{i \rightarrow j}}{W_{j \rightarrow i}} \geq 0, \quad (2)$$

provided $\varepsilon_t \geq 0$. Thus the DEQF pressure yields *non-negative coarse-grained entropy production*—a direct realization of the *Second Law of Thermodynamics* at macroscopic scale. In the limit $\varepsilon_t \rightarrow 0$ one recovers time-reversal symmetry; equality $\dot{S} = 0$ holds only at detailed balance (thermodynamic equilibrium).

Remarks.

- The factor $\tau(a)$ controls how strongly the background bias accumulates over time; with $\tau(a) = \tau_0 a^{-p}$, the effective drive $\varepsilon_t \Delta t / \tau(a)$ naturally redshifts with expansion for $p > 0$.
- No special low-entropy initial condition is assumed here; the forward orientation encoded by (P_0, U^μ) is sufficient to select the sign of $\dot{S}$ at the coarse-grained level.

5 Baryon Bias from the GUFT Lagrangian

Feynman’s time-reversal picture and a pressure-set arrow

In the relativistic path-integral/QFT viewpoint emphasized by Feynman, an antiparticle can be treated as the corresponding particle propagating *backward in time*. Concretely, a positron is an electron whose worldline is oriented opposite to the macroscopic time direction; reversing a worldline’s temporal orientation corresponds to exchanging particle and antiparticle quantum numbers. If the DEQF vacuum carries a static pressure P_0 that selects a preferred (forward) time orientation, then worldlines aligned with that orientation acquire a slightly higher statistical weight than those opposed to it. This provides a natural, sign-definite seed for a matter–antimatter imbalance: forward-time (matter) histories are marginally favored over backward-time (antimatter) histories.

Minimal effective operator

We encode the preferred orientation with a unit, future-directed selector U^μ (comoving $U^\mu = (1, 0, 0, 0)$) and a vacuum coherence time $\tau(a)$. The minimal, gauge-invariant, rotationally symmetric and CPT-odd operator that biases matter versus antimatter is

$$\mathcal{L}_{\text{int}} = \mu_t(a) U_\mu J_{B-L}^\mu, \quad \mu_t(a) = \varepsilon_t \frac{P_0 \tau(a)}{M_*^2}, \quad \tau(a) = \tau_0 a^{-p}, \quad (3)$$

where J_{B-L}^μ is the conserved $B-L$ current of the Standard Model sector, ε_t is a dimensionless orientation factor set by GUFT microphysics, and M_* is a heavy suppression scale. (With $\hbar = c = 1$, P_0 has mass dimension 4 and τ has dimension -1 , so $P_0 \tau / M_*^2$ has dimension 1, as required for a chemical potential.)

Thermal mapping to η_B

In a relativistic plasma with small chemical potentials $|\mu_i| \ll T$, a fermionic species satisfies $n_i - \bar{n}_i = g_i \mu_i T^2 / 6 + \mathcal{O}(\mu_i^3)$. Summing over all carriers of $B-L$ (effective degeneracy g_{B-L}) and dividing by the entropy density $s = (2\pi^2/45) g_* T^3$, the net baryon asymmetry after sphaleron processing is

$$\eta_B \equiv \frac{n_B - \bar{n}_B}{s} = c_{\text{sph}} \frac{15}{4\pi^2} \frac{g_{B-L}}{g_*} \frac{\mu_t}{T} \Big|_{T=T_{\text{FO}}}, \quad (4)$$

where c_{sph} is the standard sphaleron conversion factor and T_{FO} is the relevant freeze-out temperature. During radiation domination $T \propto a^{-1}$, hence with Eq. (3)

$$\frac{\mu_t}{T} \propto \left(\frac{P_0 \tau_0}{M_*^2} \right) \left(\frac{T_0}{T} \right)^{1-p} \Rightarrow \eta_B \propto \left(\frac{P_0 \tau_0}{M_*^2} \right) \left(\frac{T_0}{T_{\text{FO}}} \right)^{1-p}. \quad (5)$$

Sign, scaling, and consistency

The *sign* of η_B is fixed by ε_t : a positive ε_t (forward-time preference set by the DEQF pressure) yields $\eta_B > 0$ and thus a matter excess, in line with the Feynman time-reversal picture. The *magnitude* depends on the dimensionless combination $\varepsilon_t P_0 \tau_0 / M_*^2$ and the coherence slope p ; fitting $\eta_B \simeq 6 \times 10^{-10}$ requires $(\mu_t/T)|_{\text{FO}} \sim (1-5) \times 10^{-8}$ for representative g_* , g_{B-L} , c_{sph} (see the BBN/CMB cheat sheet). Today, local/PPN-like bounds are satisfied if $|\mu_t(z \approx 0)| \ll \text{eV}$, achieved by sufficiently large p (shorter present τ) and/or a high M_* .

How this mechanism resolves the antimatter problem

Problem. Why does the Universe contain far more matter than antimatter, with a relic baryon asymmetry $\eta_B \simeq 6 \times 10^{-10}$, when microscopic laws are (approximately) time-reversal symmetric?

Mechanism. In Feynman’s time-reversal picture an antiparticle is the corresponding particle propagating backward in time. The DEQF’s static pressure P_0 , together with the selector U^μ and coherence time $\tau(a)$, fixes a preferred (forward) temporal orientation. At low energies this appears as a CPT-odd, gauge-invariant interaction

$$\mathcal{L}_{\text{int}} = \mu_t(a) U_\mu J_{B-L}^\mu, \quad \mu_t(a) = \varepsilon_t \frac{P_0 \tau(a)}{M_*^2}, \quad \tau(a) = \tau_0 a^{-p},$$

which functions as a small, time-oriented “chemical potential” for $B-L$. In the hot plasma, forward-time (matter) worldlines acquire slightly higher statistical weight than backward-time (antimatter) ones, seeding a net charge density.

Imprinting the asymmetry. While baryon/lepton-number-changing processes are active (e.g., electroweak sphalerons and any L-violating reactions), the plasma re-equilibrates in the presence of μ_t to a nonzero

$$\eta_B = c_{\text{sph}} \frac{15}{4\pi^2} \frac{g_{B-L}}{g_*} \frac{\mu_t}{T} \Big|_{T=T_{\text{FO}}},$$

with the *sign* fixed by ε_t (forward-time preference $\Rightarrow \eta_B > 0$) and the *size* set by $\varepsilon_t P_0 \tau_0 / M_*^2$ and p . After freeze-out the generated asymmetry is conserved and the symmetric remainder annihilates, explaining the absence of large antimatter domains today.

Relation to Sakharov conditions. The DEQF-induced μ_t supplies a controlled departure from detailed balance (effective CPT/T violation at the coarse-grained level). CP violation enters through the sign/orientation parameter ε_t . Baryon/lepton number violation is provided by standard high-temperature processes (e.g., sphalerons and possible L-violating interactions); once those switch off, the asymmetry freezes in. Thus the three Sakharov ingredients are realized within this pressure-first framework.

What is—and is not—claimed

We work at the level of an effective, testable parameterization. In particular, we do *not* claim a first-principles computation of the coherence slope p or the orientation factor ε_t from GUFT microphysics. Instead, we identify and constrain the observable combination

$$\Xi \equiv \varepsilon_t \frac{P_0 \tau_0}{M_*^2},$$

which controls the freeze-out ratio $(\mu_t/T)|_{\text{FO}}$ and hence the baryon asymmetry via Eq. (4). The model makes concrete, falsifiable statements: (i) *sign*: $\eta_B > 0$ (matter excess) for $\varepsilon_t > 0$ in the Feynman time-reversal picture; (ii) *magnitude*: $(\mu_t/T)|_{\text{FO}} \sim (1-5) \times 10^{-8}$ suffices to reach $\eta_B \simeq 6 \times 10^{-10}$ with standard $(c_{\text{sph}}, g_*, g_{B-L})$; (iii) *scaling*: $\mu_t/T \propto T^{p-1}$ (radiation era) links early-universe and late-time limits. These statements permit immediate confrontation with CMB/BBN bounds (early) and laboratory/PPN constraints (today), yielding allowed regions in (Ξ, p) . A first-principles derivation of p and ε_t within GUFT is deferred to future work and will sharpen the numerical prediction without altering the present model’s sign, scaling, or testability.

Assumptions and Scope

Effective regime. We work in a controlled effective description with a small, time-oriented bias: (i) $|\mu_t|/T \ll 1$ throughout the relevant epoch; (ii) radiation domination with $T \propto a^{-1}$ and standard $g_*(T)$; (iii) electroweak sphalerons in equilibrium until $T \sim 130\text{--}160$ GeV, after which the generated asymmetry freezes in.

Minimal operator and identifiability. At low energies the only CPT-odd, gauge-invariant, rotationally symmetric operator linear in the selector U^μ that biases matter vs. antimatter is $\mathcal{L}_{\text{int}} = \mu_t(a) U_\mu J_{B-L}^\mu$ with $\mu_t(a) = \varepsilon_t P_0 \tau(a)/M_*^2$ and $\tau(a) = \tau_0 a^{-p}$. Data constrain the *identifiable* combination

$$\Xi \equiv \varepsilon_t \frac{P_0 \tau_0}{M_*^2},$$

not $P_0, \tau_0, \varepsilon_t, M_*$ separately.

What the model *predicts*.

- **Sign:** $\eta_B > 0$ for $\varepsilon_t > 0$ in the Feynman time-reversal picture (forward-time worldlines favored).
- **Magnitude:** With standard $(c_{\text{sph}}, g_*, g_{B-L})$, one needs $(\mu_t/T)|_{\text{FO}} \sim (1-5) \times 10^{-8}$ to reach $\eta_B \simeq 6 \times 10^{-10}$ via Eq. (4).
- **Scaling:** $\mu_t/T \propto T^{p-1}$ in radiation domination, linking early-universe and late-time bounds on the same (Ξ, p) .

What we *do not* claim. We do not provide a first-principles derivation of p or ε_t from GUFT microphysics here; those will sharpen numerics but do not affect the sign, scaling, or testability stated above. We also do not rely on galaxy-scale phenomenology (e.g., κ_g , α_g) for the baryon-bias result.

Falsifiability. The framework is ruled out if any of the following hold: (i) the sign prediction fails (evidence for $\eta_B < 0$); (ii) no (Ξ, p) region simultaneously fits η_B and satisfies CMB/BBN bounds on chemical potentials; (iii) today’s implied $|\mu_t(z \approx 0)|$ violates laboratory/PPN-like limits.

6 Consistency and Falsifiable Implications

- **Early–universe bounds.** Require $(\mu_t/T)_{T_{\text{FO}}}$ consistent with CMB/BBN constraints on chemical potentials; this restricts $(\varepsilon_t P_0 \tau_0 / M_*^2, p)$.
- **Local constraints.** Today $|\mu_t(z \approx 0)| \ll \text{eV}$ (from laboratory and PPN–like limits), achievable via larger p (shorter present τ) and/or high M_* .
- **Sign and scale.** The model predicts $\eta_B > 0$ (matter excess) and targets the observed magnitude $\sim 6 \times 10^{-10}$ for plausible parameter ranges.
- **Self-consistency with c and Λ .** The same P_0 used here is the invariant that produced c and Λ in Papers I–II; no additional long–range fields are introduced.

7 Limits and Outlook

We have not derived the microscopic value of p or the coefficient ε_t from first principles; the present work isolates the *scaling* and sign structure needed to confront data. A microphysical computation of $\tau(a)$ and ε_t within GUFT is the natural next step, together with a dedicated analysis of BBN/CMB bounds on μ_t .

8 Glossary of Symbols

P_0 (DEQF static pressure); U^μ (unit, future–directed selector); $\tau(a)$ (vacuum coherence time, τ_0 today, slope p); M_* (heavy scale); ε_t (dimensionless orientation factor); g_* (relativistic degrees of freedom); g_{B-L} (effective $B-L$ degeneracy); c_{sph} (sphaleron factor); T_{FO} (freeze–out temperature); η_B (baryon asymmetry).

9 BBN/CMB Bounds Cheat Sheet for η_B

This subsection records quick formulas and typical numbers to target the observed baryon asymmetry without committing to detailed microphysics.

Observed target.

$$\eta_B^{\text{obs}} \equiv \frac{n_B - \bar{n}_B}{s} \approx 6 \times 10^{-10}. \quad (6)$$

Minimal mapping from a small temporal bias. If a CPT-odd, time-oriented perturbation induces a small effective chemical potential μ_t that couples to the conserved $B-L$ current, then for $|\mu_t| \ll T$ (after sphaleron processing)

$$\eta_B = c_{\text{sph}} \frac{15}{4\pi^2} \frac{g_{B-L}}{g_*} \frac{\mu_t}{T} \Big|_{T=T_{\text{FO}}}, \quad (7)$$

where c_{sph} is the sphaleron conversion factor, g_* the effective relativistic degrees of freedom at freeze-out, and g_{B-L} the effective degeneracy of $B-L$ carriers.

Back-solving for the required bias. Taking representative Standard Model values

$$c_{\text{sph}} \simeq \frac{28}{79} \approx 0.35, \quad g_*(T \sim 100 \text{ GeV}) \simeq 106.75, \quad g_{B-L} \in [10, 30], \quad (8)$$

Eq. (7) implies

$$\frac{\mu_t}{T} \Big|_{\text{FO}} \approx \eta_B^{\text{obs}} \frac{4\pi^2}{15} \frac{g_*}{c_{\text{sph}} g_{B-L}} \sim (1-5) \times 10^{-8}, \quad (9)$$

with the range set by $g_{B-L} \in [30, 10]$ respectively.

Consistency checks (order-of-magnitude).

- *Early universe:* CMB/BBN bounds on small chemical potentials are typically $\lesssim 10^{-2}$ per flavor; the target above is many orders smaller and broadly consistent.
- *Today:* If $\tau(a) = \tau_0 a^{-p}$, then $\mu_t/T \propto T^{p-1}$. For $p \approx 1$ this ratio is roughly constant, giving $\mu_t(z \approx 0) \sim (10^{-8}) T_0 \sim 10^{-12} \text{ eV}$, safely beneath lab/PPN-like limits.

Parameter inversion (quick fits). If your model predicts $\mu_t \propto \mathcal{C} T^p$ at high T , then

$$\mathcal{C} \approx \frac{\mu_t}{T} \Big|_{\text{FO}} T_{\text{FO}}^{1-p} \sim (1-5) \times 10^{-8} \times T_{\text{FO}}^{1-p}, \quad (10)$$

which you can plug back into Eq. (7) to match η_B^{obs} .

10 Conclusion

We have argued that a single invariant of the Dark Energy Quantum Field—the static pressure P_0 —accounts not only for the emergence of c and Λ (as established in our earlier work) but also for three macroscopic features of our universe: a preferred temporal orientation (the arrow of time), non-negative coarse-grained entropy production, and a small forward-time bias that favors matter over antimatter. In our formulation, P_0 acts with a unit timelike selector U^μ and a vacuum coherence time $\tau(a)$ to introduce a controlled time-odd correction to detailed

balance (fixing the direction of entropy increase) and a minimal, CPT-odd coupling in the GUFT Lagrangian,

$$\mathcal{L}_{\text{int}} = \mu_t(a) U_\mu J_{B-L}^\mu, \quad \mu_t(a) = \varepsilon_t \frac{P_0 \tau(a)}{M_*^2}, \quad \tau(a) = \tau_0 a^{-p},$$

which yields a baryon asymmetry $\eta_B \propto (\mu_t/T)$ evaluated at freeze-out. The *sign* of the asymmetry is fixed by the DEQF-selected temporal orientation ($\varepsilon_t > 0$ favors matter), while its *magnitude* depends on the dimensionless combination $\varepsilon_t P_0 \tau_0 / M_*^2$ and the coherence slope p .

Falsifiable implications

1. **Matter excess and scale:** With representative early-universe inputs ($c_{\text{sph}}, g_*, g_{B-L}$), the required ratio is $\mu_t/T|_{\text{FO}} \sim (1-5) \times 10^{-8}$ to reach $\eta_B \simeq 6 \times 10^{-10}$. This is an immediate quantitative target for the model.
2. **Early-universe consistency:** The same $(\mu_t/T)_{\text{FO}}$ must lie beneath CMB/BBN bounds on small chemical potentials—comfortably satisfied at the 10^{-8} level.
3. **Local constraints:** Today one requires $|\mu_t(z \approx 0)| \ll \text{eV}$; this is naturally achieved for $p \gtrsim 1$ and/or sufficiently large M_* .
4. **Unified origin:** The parameters that fit η_B are consistent with the pressure scale already implicated in c and Λ , linking all four phenomena to the same invariant P_0 .

Near-term next steps

- **Microphysics:** Derive p and ε_t within GUFT rather than treating them as effective parameters.
- **Cosmological bounds:** Convert CMB/BBN limits on chemical potentials into explicit constraints on $(\varepsilon_t P_0 \tau_0 / M_*^2, p)$ for benchmark T_{FO} .
- **Laboratory/PPN checks:** Translate existing CPT-odd vector limits into bounds on $\mu_t(z \approx 0)$, ensuring alignment with the early-universe fit.
- **Extensions:** Explore sector-specific consequences (e.g., neutrino sector, CP/CPT tests) and possible small imprints on nonequilibrium phenomena tied to $\tau(a)$.

In short, a single pressure-first mechanism— P_0 with (U^μ, τ) —provides a coherent account of c , Λ , the arrow of time, entropy production, and the observed baryon asymmetry, while remaining sharply testable by early-universe and local constraints.

References

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